Experimental study of the behaviour of PEEK CF30 bearing to cyclical loading and variable rotational speed

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Abstract :

Rotating elements are widely used in machinery applications. Infra red camera based thermography monitoring of these devices can be of huge interest in practice as it can provide a mean to operate real time supervising of such critical devices. This work dealt with the feasibility of using infrared thermography in the particular context of PEEK CF30 and carbon steel F114 manufactured bearings. A test rig was built with the possibility to operate at various rotational speeds of bearings over a large range. Various tests were performed and experimental thermograms were obtained by means of a static high-speed thermographic camera that recorded temperature variations in various cursors of the tested bearing. The duration of tests was fixed at 15 minutes. Comparison of the obtained results has shown different behaviours for PEEK CF30 and carbon steel F114. The issue of correlating a particular damage with the observed temperature changes was discussed.

Key words: **Rotating machinery, PEEK CF30 bearing, Carbon steel F114 bearing, Infra-Red Thermography**

1 Introduction

Due to their high strength/density ratio, Short Fiber Reinforced Plastics (SFRPs) are very attractive materials in the automotive industry as they can achieve optimisation of weight and cost. Their ability to be machined into complex shaped parts with possible high production rates, have yielded growing use of SFRP in parts manufacturing. Nowadays, their use as load bearing components has been greatly initiated [1-3].

Rotating machinery covers a broad range of mechanical equipments and assures a key role in modern industries. Due to the continuous necessity of enhancing productivity, rotating machinery is required to run with minimum interruptions and with the largest possible life, as failure events are very costly [4].

One of the biggest problems in mechanical systems is that they can be exposed to high temperatures. The excessive heat they endure can be generated by friction, eventual cooling system degradation, material loss or blockages. Excessive of friction can be caused by wear, misalignment, over or under lubrication. Abnormal heating, such as that occurring in a misaligned coupling, constitutes a warning signal that could precede a dramatic rupture. If left alone at the stage when the excess of temperature is observed, a bearing component may endure huge wear or further damage which could deteriorate then even the other components parts.

Infrared Thermal Imaging has gained increasing interest in the field of mechanical components diagnostics as this technique can enable to localize potential problematic areas by monitoring overheating [5]. As heat is often produced within a component that is not visible directly to the camera, only the part of heat which conduct up through the material and manifest itself as a pattern on the surface of the object can be sensed by an infrared camera[6]. When overheating is detected, other techniques can be employed to further determine where the problem actually lies and with which extent.

Inspecting bearings is an activity that can be conducted by means of infrared thermography. Abnormal friction within a bearing will generate heat and cause rise of the bearing's surface temperature. This thermal signature, when detected, is an indication of a potential bearing problem. This can be the result of under-lubrication, over-lubrication, poor maintenance or simply a weared bearing that should be replaced.

This paper presents an experimental study on the damage detection of bearings based on temperature measurement by IR Camera. The proposed work is a first stage with the aim to obtain and analyse experimental measurements in this field.

2 Experimental procedure

Samples of the PEEK CF30 plastic bearing and the carbon steel F 114 bearing, as those shown in Fig.1, were installed between a power and a measuring bearing device. Tests were conducted in an air conditioned laboratory environment where ambient temperature was controlled. The test rig configuration and IR camera used in this experiment were as shown in Fig. 2. The infrared camera used in this experiment has the reference PCE-TC 3. The manufacturer declares that it offers a measurement accuracy of ±2°C within the temperature range of -10ºC to 250ºC, and with a sensitivity of 0.15ºC. Tests were performed at constant loading, where the loading was applied by means of cylindrical weights units having each the mass value of 2.5 kg. By monitoring the driving motor speed, the experiment can be performed with the following rotating speeds 300, 600, 900, 1200 and 1500 rpm. The test duration was fixed at 15 min. For each tested sample, a thermogram presenting temperature variations as sensed by the IR camera is obtained.

While using infra red thermometry accuracy is a main concern. This depends in fact on many factors, including the detector being used, the material properties of the target and even the temperature of the target itself. Depending on all of these factors, temperatures can be measured to accuracies of fractions of a degree C, or to a bad range as high as 5 to 20 degrees. In the actual experiment, preliminary tests have shown that the achieved accuracy was largely within the margin error of 5 degrees. This is important, as otherwise repeatability of testing results is not guaranteed yielding then false detections.

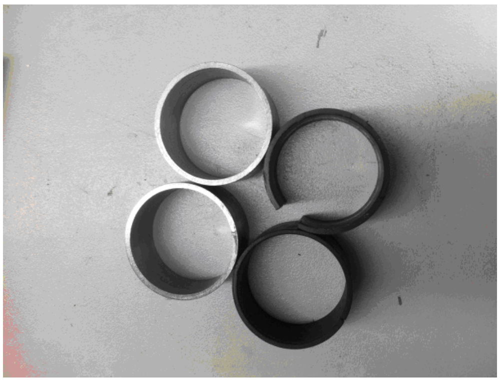
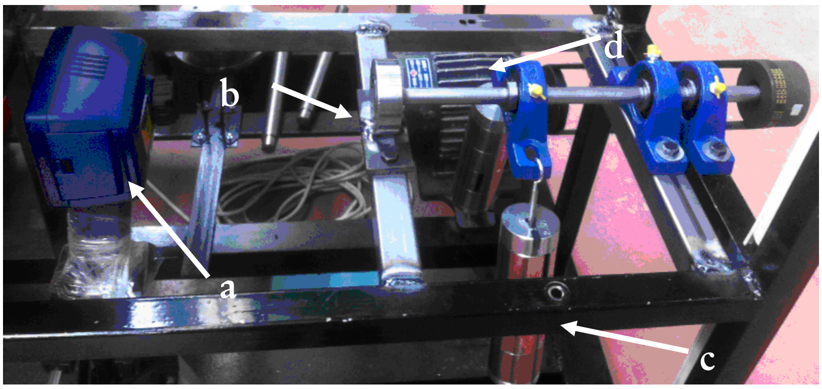


FIG. 1 – PEEK CF30 plastic and carbon steel F114 bearings



a) IR camera PCE-TC 3 b) Bearings c) Circular weights d) Servo motor

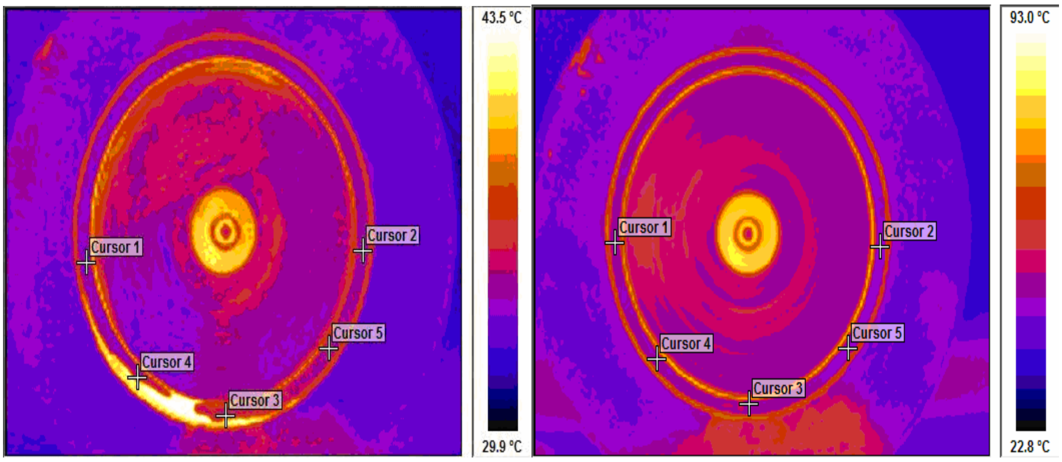
FIG. 2 – Experimental apparatus for bearing test

3 Results and discussion

When considering a higher range of bearings rotational speed, one of the most fundamental concerns to deal with is how to supervise lubrication. In this study, SAE 1030 was used in order to avoid that carbon Steel F114 bearings suffer excess overheating. On the opposite, lubrication was not required when using PEEK CF30 plastic bearings as the maximum reached temperature was well below the heat resistance temperature, which is for PEEK about 250 ºC. Temperature oscillations depend on the thermal and mechanical properties of the material and also on the heat source and ventilation conditions. In the present work, a high-speed IR camera is used to monitor temperature changes during test runs, as tracking real-time temperature rise is essential in order to estimate any presence of overheating events.

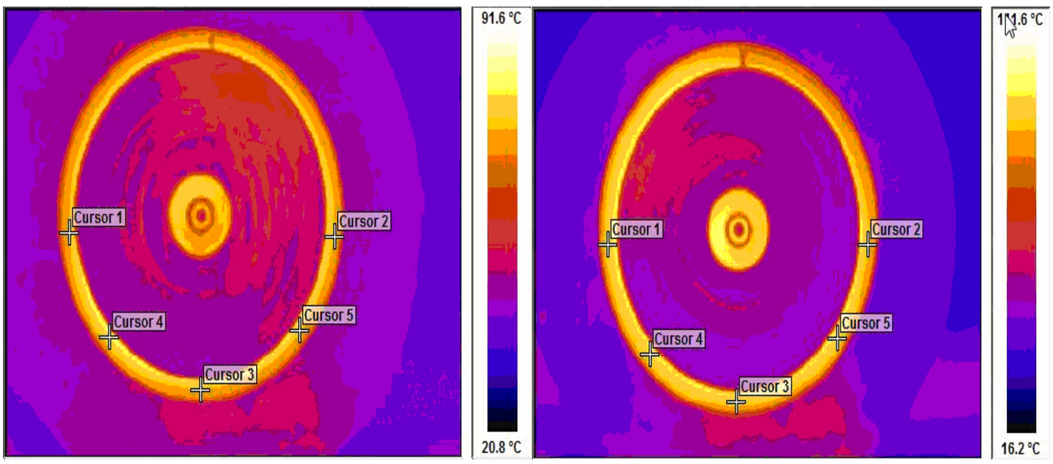
Figures 3 and 4 show thermographic charts of bearing devices that provide quantitative assessment of temperature rise during system operation. The main advantage of this infrared thermographic technique is that it is a contact less scanning method which enables real-time non-destructive testing and diagnosis of devices during their normal work conditions, without the need to stop production or to dismantle any component. The only requirement is that the supervised surface should be accessible to the camera focus.

Figure 3 presents thermographic images for Carbon Steel F114 bearing, while figure 4 presents those of PEEK CF30 bearing. Cursors have been placed on critical points in order to track temperature variations in these particular points.



a) 300 rpm b) 1500 rpm

FIG. 3 – Thermographic quantitative imaging's results for Carbon Steel F114 Bearing



a) 300 rpm b) 1500 rpm

FIG. 4 – Thermographic quantitative imaging's results for PEEK CF30 Bearing

As shown in figures 3 (a-b) that are associated to Carbon Steel F114 bearings, the maximum temperature reached is 43.5 °C for 300 rpm, whereas at 1500 rpm it increases till the value of 93 °C.

From figures 4(a-b) which are those of PEEK CF30 bearing, the maximum temperature reached was 91.6 ºC at 300 rpm, while at 1500 rpm it has reached 111.6 °C.

Figures 5 and 6 recall the main obtained results for the different tested rotational speeds in terms of temperature rise. Five data charts are given for each bearing material.

Continuous profiles for which temperature changes do not undergo abrupt variations reveal that no damage event is occurring. However, a brusque jump of temperature at a cursor location should be though of to be related to appearance of a heat source following some localized damage undergone near from the cursor location. In case of figure 5, the 20°C increase at 900 rpm for cursor 3 constitutes an outstanding event. The temperature exceeds that of the other cursors for over the last 9 minutes. More likely, a local degradation of the carbon steel F114 bearing was experienced. This can admit various origins, since cyclic tests can generate complex thermal mechanical phenomena. A local damage associated to the presence of debris or oxidation of the interface which induces decrease of thermal diffusivity of the material is a possible explanation for the observed temperature rise. Posterior examination of the cursor 3 location has revealed the presence of a local degradation of the bearing.

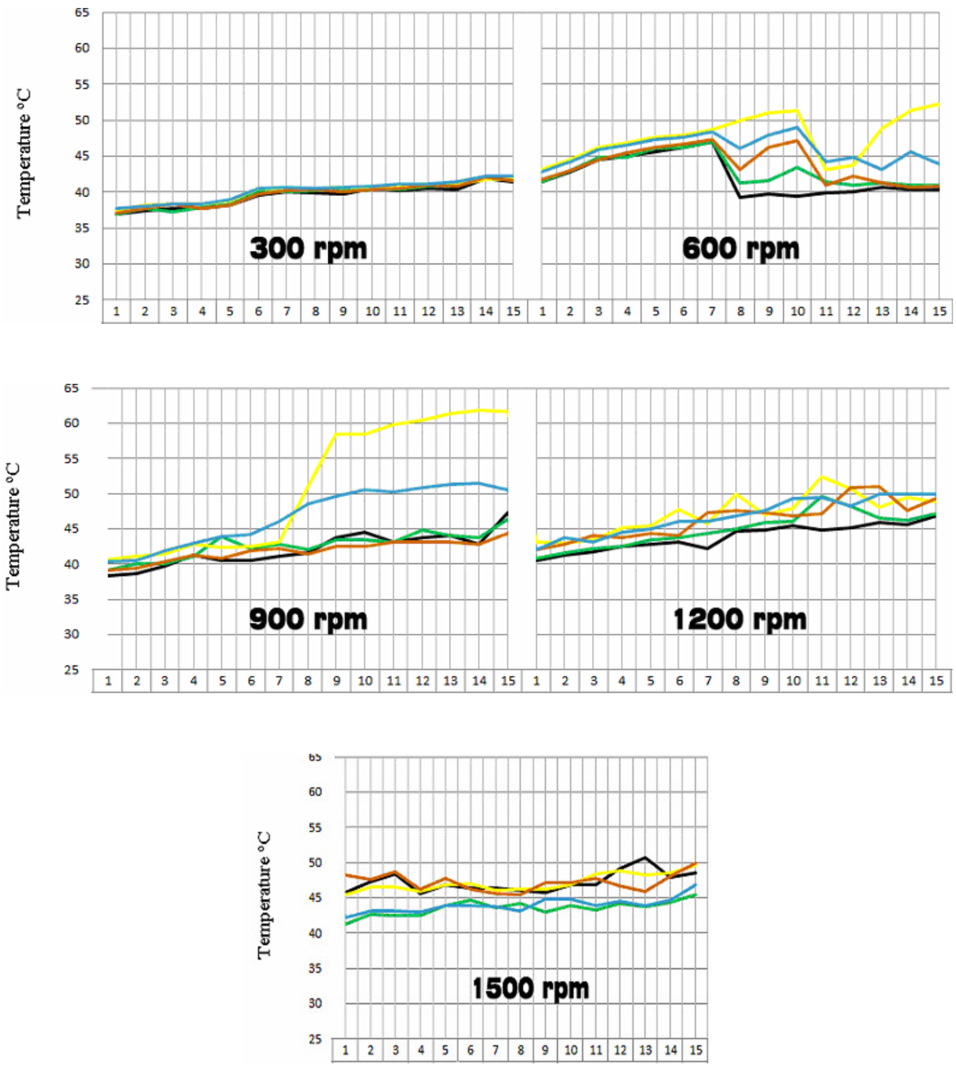


FIG. 5 – Evolution of the temperature of the Carbon steel F114 bearing according to the rotational speed level (Increase in rotational speed every 15 minutes)

In case of figure 6, the most important thing to mention is that PEEK CF30 based bearing has supported without any problem a maximum temperature of 138 °C, recorded in Cursor 4. The peak temperatures that appeared for speeds 900 rpm and 1200 rpm reveal the presence of a distributed event as all cursors recorded almost the same temperature. Probably, the cyclic tests caused damage at the interface between the fiber and the matrix, and significant changes affected mechanical properties of the composite at the instant when the peak appeared. Debonding and oxidation that are likely to occur at the bearing interface have probably decreased thermal diffusivity and thermal conductivity of the material. Internal friction caused by fiber-matrix sliding has then increased and this is believed to be the cause of the observed temperature jump which concerned all cursors and which disappeared once the contact surface recovered its normal state. This is not the unique explanation, because thermoelastic instability that happens for some critical speed can be behind the observed peaks. This phenomenon may have disappeared just because the contact materials have hardened. Correlating thermograms with specific degradations that are present should be conducted through extensive extra tests in order to avoid misinterpretations. The first merit of the method is that it is able to alert for the presence of a potential risk, and this information can be used to supervise in better conditions serviceability tasks. Here for example, the abnormal temperature experienced at cursor 3 of the carbon steel F114 bearing would be an alarm if its duration is enough lengthy.

In the literature, classification of IR thermography results have been performed and has indicated that this system could be employed to assist in monitoring machine condition and diagnosing machine faults [4,7,8]. Our prospects are to achieve such a classification in future works.

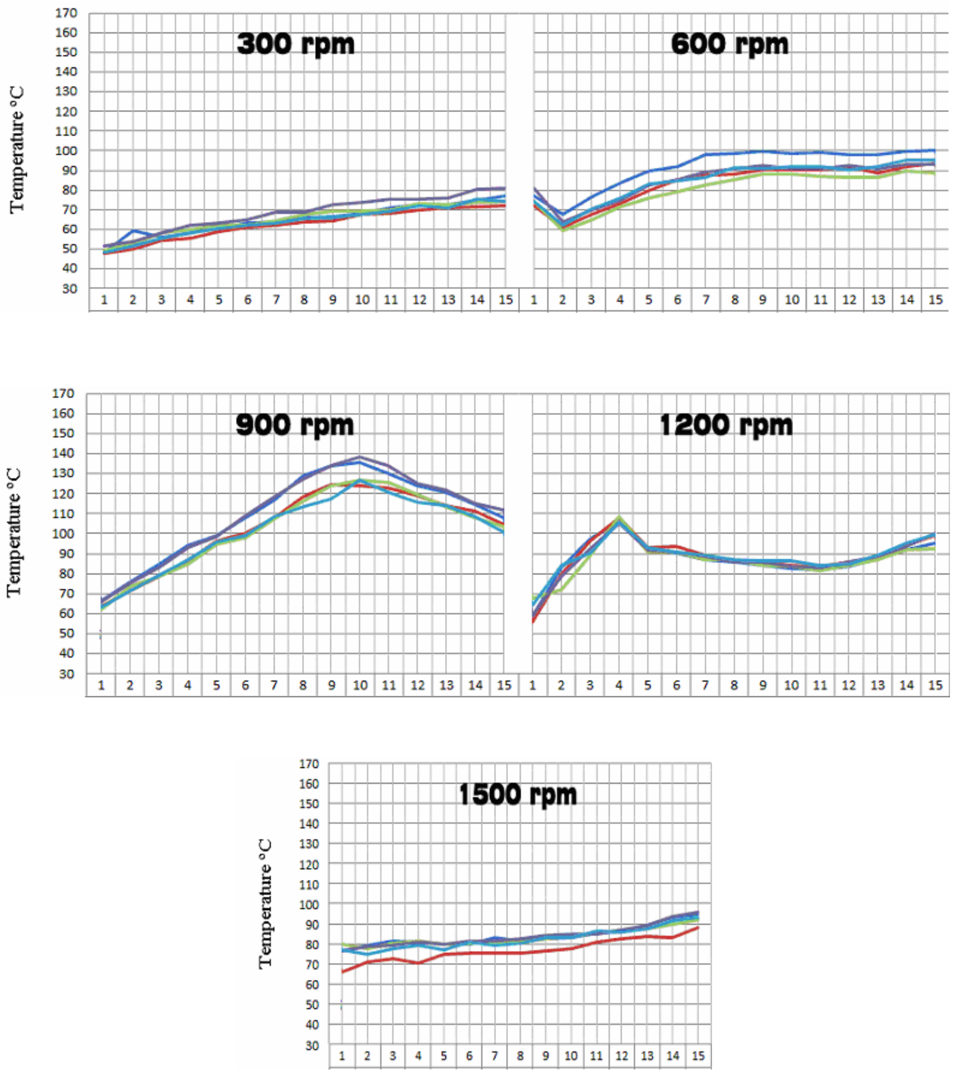


FIG. 6 – Evolution of the temperature of the PEEK CF30 bearing according to the rotational speed level (Increase in rotational speed every 15 minutes)

4 Conclusion

This paper presented an experimentally based method intended to be used for online temperature measurement of rotating machine bearings in order to detect abnormal temperature jumps. This information can be further used to detect wear or other defects which may occur at the bearing interface. Two different materials used in manufacturing of bearings that include PEEK CF30 and carbon steel F114 were tested. IR imaging has been used to successfully capture thermal transients as function of the operating speed and time. The first results have shown that monitoring temperature transient is quite possible with the proposed methodology. It was possible also to discuss predicting typical defects with the obtained thermograms. More work should be done in order to correlate the presence of characteristic damages with specific thermograms.

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